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XFEM: Exploratory Research into the Extended Finite- Element Method, FY02 LDRD Final Report

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XFEM: Exploratory Research into the Extended Finite-Element Method

FY02 LDRD Final Report

This report is one of two components, the first an overview document outlining the goals and results of the XFEM LDRD project, and the other (titled “Structured Extended Finite Element Methods of Solids defined by Implicit Surfaces”) detailing the scientific advances developed under FY01/FY02 LDRD funding.

Overview

The XFEM (Extended Finite-Element Method) Engineering LDRD/ER Project was motivated by three research and development goals:

- (1) the extensions of standard finite-element technology into important new research venues of interest to the Engineering Directorate,
- (2) the automation of much of the engineering analysis workflow, so as to improve the productivity of mesh-generation and problem setup processes, and
- (3) the development of scalable software tools to facilitate innovation in XFEM analysis and methods development.

The driving principle behind this LDRD project was to demonstrate the computational technology required to perform mechanical analysis of complex solids, with minimal extra effort required on the part of mechanical analysts. This need arises both from the growing workload of LLNL analysts in problem setup and mesh generation, and from the requirement that actual *as-built* mechanical configurations be analyzed. Many of the most important programmatic drivers for mechanical analysis require that the actual (e.g., deformed, aged, damaged) geometric configuration of the solid be deduced and then accurately modeled: for this programmatic need, XFEM provides one of the only accurate methods available that can provide high-fidelity results.

Results

The XFEM LDRD project ran for two years of its proposed three-year duration, and achieved many of its most important goals: in fact, it achieved all of its key scientific research goals, which is the primary reason why the project finished early.

Some of the key results from the XFEM LDRD include the following:

- New analysis technology for modeling crack propagation in brittle solids, and for related problems of localization in nonlinear material response,
- Automated detection of mechanical boundaries from data obtained via non-destructive evaluation (e.g., CT scans of mechanical objects), via the application of novel computational algorithms originally intended for computer graphics and visualization applications,
- Automated XFEM mesh generation capabilities utilizing these boundary-detection algorithms to determine material boundaries, and

- Strategies for developing new enrichment functions to extend the range on nonlinear inelastic response to include new physical behaviors, e.g., ductile fracture.

All of these results were achieved after two years of the project's duration, and so this project was concluded early with excellent overall results. The only remaining project goal arose from the desire to cast all of these XFEM technology gains into a scalable high-performance computational package using the Terascale framework (a finite-element framework intended to facilitate developing new finite-element technologies that will run on ASCI-class supercomputers). Since this novel computational framework is only now becoming available for use, the XFEM LDRD project was ended early, and this remaining *developmental* topic will be pursued under different funding sources.

The Northwestern University component of the work (see the second report for details) demonstrated the application of XFEM technology towards a general CAD/CAE capability for characterizing the material and geometric configuration of a solid, and then for simulating its physical response to loads. The characterization process was developed using implicit surface definitions that cast material boundaries into the form of level surfaces of implicitly-defined functions. This technique permits automated mesh generation from a structured set of voxels, such as would be obtained from CT scans of the mechanical object. Internal details can be handled similarly using this approach.

Once the XFEM mesh is generated, the physical analysis proceeds in a manner similar to that found in conventional finite-element analysis, save for the use of enrichment functions that are designed to capture local physical response such as cracking, motion of parts along a material interface. By utilizing the partition-of-unity approach that underlies finite-element modeling, these localized material behaviors can be readily captured and computationally simulated with little intervening effort on the part of the mechanics analyst.

Verification and validation studies carried out at Northwestern demonstrate that the new XFEM techniques maintain nearly all the desirable characteristics of conventional finite-element models (e.g., rates of convergence, general applicability), while permitting finite-element problems to be set up with much less analyst effort, and while facilitating the inclusion of localized material response that is notoriously difficult to capture using conventional finite-element techniques.

Conclusions

Extended finite-element techniques open the door to a wider range of engineering problems that can be analyzed using computational simulation techniques. This LDRD permitted LLNL stakeholders to develop new mechanical analysis techniques that preserve the advantages of conventional finite-element techniques, while gaining the capability to model material localizations, and to perform these computational models with substantially less effort on the part of the finite-element analyst. After two years of funding, the project achieved all of its scientific goals, and hence the LDRD project was closed after finishing its most fundamental goals ahead of schedule.